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Coiling in Patients with Unruptured and Ruptured Brain Aneurysms

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ABSTRACT

The role of endovascular procedures represents a complete diagnostic and therapeutic revolution in the diagnosis and treatment of brain aneurysmal changes. A brain aneurysm is a pathological focal dilation of an artery in the brain. The vessel expands in the form of a sac of varying degrees, causing the aneurysm wall to become thin and rupture without warning.

***Aim:** To assess the risk factors in patients with cerebral aneurysms, the location and type of brain aneurysms, and to evaluate complications during and within 6 months after endovascular treatment, as well as to assess the value of interventional endovascular radiology procedures between non-bleeding and bleeding aneurysms.*

***Materials and Methods:** The study analyzed 80 patients sent to the Institute of Radiology for diagnosis and treatment of brain aneurysms. In the diagnostic phase of aneurysm treatment, we used CT angiography, magnetic resonance angiography (MRA) of the brain, classical puncture angiography via Seldinger through a biplane angiograph, and in the therapeutic treatment, i.e., coiling, we used a biplane angiograph, appropriate vascular catheters of various shapes and sizes, microcatheters and wires, specially designed coils and stents, as well as appropriate medicinal preparations, iso-osmolar iodinated contrast medium.*

***Results:** In this study, the gender structure of patients with ruptured and unruptured aneurysms was significantly different. Ruptured aneurysms were significantly more frequently diagnosed in male patients (84.38%) compared to the female population (62.5%). There was no statistically significant difference in the average age between patients with ruptured and unruptured aneurysms (55.8 ± 9.5 vs 56.8 ± 12.3 years). A statistically significant difference was detected in the distribution of small, large, and giant aneurysms between the groups of ruptured and unruptured aneurysms, showing that small aneurysms were insignificantly more frequently bleeding (77.19% vs 56.52%), large aneurysms were insignificantly more frequently non- bleeding (26.09% vs 21.05%), and giant aneurysms were significantly more frequently non- bleeding (17.39% vs 1.75%). Coiling intervention was performed in 78.75% of patients, while the remaining 21.25% underwent a combined method (7 had a stent placed, 10 had a flow diverter). Recanalization was performed in 16.25% of patients. Bleeding complications occurred in 22.5% of patients, while procedural complications were registered in 6.25% of patients.*

Repeat treatment due to recanalization or bleeding complications was performed in 8.75% of patients. During the intervention or in the early post-intervention phase up to 6 months, 4 patients died, resulting in a lethality rate of 5%. Aneurysms were non-bleeding (unruptured) in 28.75% and bleeding (ruptured) in 71.25% of patients. Regarding the type of bleeding, 40% of patients had only subarachnoid hemorrhage, 11.25% had intracerebral hemorrhage, 17.5% had intraventricular hemorrhage, and 2.5% had subarachnoid hemorrhage with both intracerebral and intraventricular hemorrhage.

***Conclusion:** Endovascular treatment of brain aneurysms is a minimally invasive method of choice with optimal benefit for patients during the procedure and in the post-therapeutic period, contributing to full recovery. The method is emerging as the gold standard compared to other therapeutic surgical procedures.*

Keywords
Endovascular treatment, Brain aneurysms, Subarachnoid hemorrhage, Coiling, Seldinger puncture angiography.

Introduction
A brain aneurysm is a pathological dilation or ballooning of a blood vessel in the brain, characterized by abnormal enlargement of the vessel. The most common types are saccular (berry) aneurysms, located at the branching points of arteries, predominantly in the Circle of Willis at the base of the brain. The rupture of the blood vessel usually results in subarachnoid hemorrhage (SAH) or intracranial hemorrhages [1-4]. A cerebral aneurysm can persist as unruptured, leak and cause minor subarachnoid hemorrhage, or rupture resulting in massive subarachnoid hemorrhage and formation of an intracerebral hematoma, clinically manifesting as hemorrhagic stroke. Typically, a ruptured brain aneurysm occurs in the space between the brain parenchyma and the meninges that cover the brain. This type of hemorrhagic stroke is called subarachnoid hemorrhage. In fact, 90% of subarachnoid hemorrhages result from ruptured aneurysms. In the event of a ruptured aneurysm, 33% of patients are reported to die before reaching the hospital, 37% sustain major neurological deficits, and only 30% have an acceptable neurological status. A ruptured aneurysm rapidly becomes life-threatening and requires timely, urgent medical treatment. However, most brain aneurysms do not rupture and are often discovered incidentally during investigations for other pathological health conditions. They pose a health risk due to the potential for rupture. Treatment of patients with unruptured brain aneurysm is elective, depending on the symptoms, location, and size of the aneurysm, aiming to prevent future rupture. The optimal time for aneurysm treatment is before rupture, indicating that timely, early diagnosis and treatment reduce morbidity and mortality from brain aneurysms [3-8].

Different prevalence of brain aneurysms has been reported between men and women. In many published results, they are more common in men, but the incidence increases in postmenopausal women. In children, the incidence is low, suggesting that aneurysms develop and grow over a long period. Unruptured intracranial aneurysms are relatively common in the general population, found in 3.2% of the adult population (average age 50 years) worldwide, and are discovered more frequently due to the widespread use of high-resolution magnetic resonance scanning. A large percentage of brain aneurysms will never rupture. For example, out of 1 million adults in the general population with an average age of 50 years, only 0.25% will rupture [3]. Aneurysms typically form at arterial bifurcation points, as these areas are the weakest. Occasionally, cerebral aneurysms may be present at birth, usually resulting from an abnormality in the artery wall. The exact mechanisms by which cerebral aneurysms develop, grow, and rupture are unknown, but are considered multifactorial. The precise molecular pathways underlying the multifactorial natural history of intracranial aneurysms remain largely unknown, posing a challenge in neurovascular research. Wall stress is one of the causes of aneurysm development through endothelial dysfunction that induces an inflammatory cascade and vascular remodeling. Angioarchitecture, age over 60 years, female gender, hypertension, smoking, alcohol abuse, and hypercholesterolemia also contribute to growth and rupture. Improvements in aneurysm wall visualization techniques and targeted therapies against the inflammatory cascade may significantly alter the natural history of cerebral aneurysm formation and development [9]. Sometimes, brain aneurysms result from inherited risk factors, including connective tissue disorders that weaken arterial walls, arteriovenous malformations, and have also been described in polycystic kidney disease. A history of aneurysm in a first-degree family member (child, sibling, or parent) suggests a higher risk of rupture in aneurysms detected in family members. The greatest risk occurs in individuals with multiple aneurysms who have already experienced a previous rupture or bleeding [2,3,5].

Risk factors described in the literature that may cause the occurrence and complications include untreated hypertension, smoking, hypercholesterolemia, and other known modifiable risk factors. Substance abuse, particularly cocaine or amphetamine, increases the risk of aneurysm development. Unusual risk factors include cranial trauma, brain tumors, and infection in the arterial wall (mycotic aneurysm) [2,3,5,9].

Aneurysms are classified by size into small aneurysms (diameter less than 11 millimeters), large (diameter between 11 and 25 millimeters), and huge or giant aneurysms (diameter more than 25 millimeters). Aneurysms also vary by shape: saccular aneurysms (having a neck, sac, and apex or dome), fusiform aneurysms which can be dissecting (post-traumatic as the most common form) and blister aneurysms as lateral outpouching without a visible neck. Saccular giant aneurysms pose a particularly high risk of rupture [3,5,7,8].

Endovascular coiling or coiling is a procedure performed to block blood flow into an aneurysm (a weakened area in the artery wall). This method is a minimally invasive technique, meaning that no incision in the skull is needed to treat the brain aneurysm and it does not cause additional complication to the already affected area. Instead, a catheter is used to reach the aneurysm in the brain. During endovascular coiling, the catheter is guided from the groin up to the artery containing the aneurysm. Platinum coils are then released. The coils cause clotting (embolization) of the aneurysm and, in this way, prevent blood from entering it.

Aim
To evaluate the value of interventional endovascular radiology procedures – coiling, in ruptured and unruptured aneurysms, as well as to assess complications and mortality during the intervention, in the early post-intervention phase and up to 6 months in patients who underwent endovascular procedure.

Materials and Methods
The study analyzed 80 patients indicated for diagnosis and treatment with symptoms of cerebral aneurysm. The study included patients with incidentally discovered aneurysms during diagnostic procedures for neurological symptoms. Patients included in the

study were followed for 6 months regarding the occurrence of complications and mortality.

Inclusion criteria were patients with cerebral aneurysm (small, large, giant), ruptured or unruptured, and age over 18 years.

Several methods were used for the diagnosis of cerebral aneurysms:
- **Computed Tomography of the Brain (CT):** This was usually the first method used to determine whether there is intracranial hemorrhage.
- **Computed Tomographic Angiography (CTA) of the Brain:** After the application of contrast, this method facilitated the diagnosis of cerebral blood vessels and could indicate the presence of an aneurysm with detailed analysis and appropriate measures for further treatment.
- **Magnetic Resonance Imaging (MRI):** This method used magnetic fields and radio waves to provide detailed images of the brain, either as 2-D sections or 3-D images with special software solutions. With Magnetic Resonance Angiography (MRA), it was possible to assess arteries in detail and detect the presence of an aneurysm.
- **Digital Subtraction Angiography (DSA) or Seldinger Puncture Angiography,** also known as cerebral angiogram, involved placing a thin, flexible tube (catheter) into a large artery, usually the femoral artery, which travels through the aortic arch, past the heart, to the arteries in the brain. Iodinated contrast material is injected into the catheter, traveling to the cerebral arteries. A series of X-ray images can reveal details about the condition of the arteries and diagnose an aneurysm, as well as real-time hemodynamics. The method is minimally invasive and usually used when other diagnostic tests do not provide sufficient information. DSA or Seldinger puncture angiography is a key method (gold standard) in the therapeutic approach to completely resolving the aneurysm by coiling, regardless of whether it is a bleeding or non-bleeding aneurysm.

The examinations provided data on the location, size, and condition of the aneurysm, i.e., ruptured/unruptured. The time of conducting the endovascular procedure "coiling" after the diagnostics was analyzed. The outcome data of the interventions were analyzed: successful, unsuccessful, complications, death, as well as postoperative course data including early post- intervention course up to 6 months.

Patients were divided into two groups based on the type of aneurysms:
1. Treated non-bleeding aneurysms with interventional endovascular radiology procedures – coiling.
2. Treated bleeding aneurysms with interventional endovascular radiology procedures – coiling.

The endovascular coiling procedure is performed through an initial guiding catheter with the insertion of a microcatheter and microwire. The coil is attached and inserted through the microcatheter. When the microcatheter and wire reach the aneurysm and are placed in the aneurysm, the wire is withdrawn, and the coils are placed. The coils are released into the aneurysm sac using electrical current, closing the aneurysm sac. The coil is left permanently in the aneurysm. Depending on the size of the aneurysm, more than one coil may be needed for complete exclusion from circulation. The coils used in this procedure are made of soft platinum metal. These coils are very small and thin, with different sizes. Fluoroscopy aids in this procedure. The catheter, inserted into an artery in the groin, is guided with a small wire inside the catheter along the blood vessel to reach the area of the aneurysm. The doctor uses fluoroscopy to guide the catheter to the location of the aneurysm in the brain.

Statistical Analysis

The statistical analysis of the data obtained from the research was performed using the statistical program SPSS 23.0. The Kolmogorov-Smirnov test and Shapiro Wilk's test were used to test the normality of the data distribution. The obtained data are presented in tables and graphs. Categorical (attribute) variables are shown with absolute and relative numbers. Numerical (quantitative) variables are presented with mean, standard deviation, minimum and maximum values, median value, and interquartile range. For comparison of groups with ruptured and unruptured aneurysms, non-parametric and parametric tests for independent samples were used (Chi-square test, Fisher exact test, Student t-test). Statistical significance was defined at the level of $p<0.05$.

Results

The study analyzed 80 patients with confirmed cerebral aneurysms, investigated due to present symptoms of cerebral aneurysm. Of the analyzed patients, 48 (60%) were women, and 32 (40%) were men. Regarding age, patients had an average age of 56.1 ± 10.3 (ranging from 31 to 84 years). The distribution by gender and age is shown in Table 1.

Table 1: Statistical analysis of patients with cerebral aneurysms by gender and age.

Variable	n (%)
Gender	
Female	48 (60)
Male	32 (40)
Age years	
(mean ± SD) (min – max)	56.1 ± 10.3 (31 – 84)

Aneurysms were non-bleeding (unruptured) in 23 (28.75%) patients, and bleeding (ruptured) aneurysms were diagnosed in 57 (71.25%) patients (Chart 1). Regarding the type of bleeding, 32 (40%) patients had only subarachnoid hemorrhage, 9 (11.25%) patients had intracerebral hemorrhage, 14 (17.5%) patients had intraventricular hemorrhage, and 2 (2.5%) patients had subarachnoid hemorrhage with both intracerebral and intraventricular hemorrhage.

The gender structure of patients with ruptured and unruptured aneurysms was significantly different ($p<0.05$). Ruptured aneurysms were significantly more frequently diagnosed in male patients – 27 (84.38%) vs 30 (62.5%). Patients with ruptured and unruptured aneurysms had similar ages, meaning the difference in average age between these two groups of patients was not statistically significant (55.8 ± 9.5 vs 56.8 ± 12.3 years), as shown in Table 2.

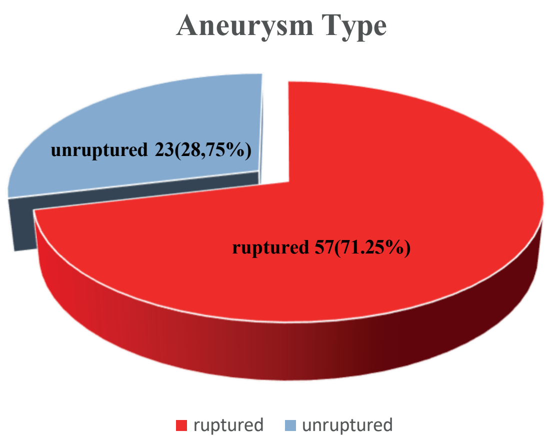

Chart 1: Distribution of ruptured and unruptured aneurysms.

Table 2: Statistical analysis of patients with ruptured and unruptured brain aneurysms by gender and age.

Variable		Ruptured Aneurysm			p - value
		n	Yes n (%)	No n (%)	
Gender	женски	48	30 (62.50)	18 (37.50)	X^2=4.5 *p=0.034 (p<0.05)
	машки	32	27 (84.38)	5 (15.63)	
	n	57		23	t=0.4
Age Years	mean ± SD	55.8± 9.5		56.8 ± 12.3	p=0.69
	min – max	31 – 84		31 75	

X^2(Pearson Chi-square); t (Student t-test)
*p<0.05

Both posteriorly located aneurysms were bleeding (Table 3). A statistically significant difference was detected in the distribution of small, large, and giant aneurysms between the groups of ruptured and unruptured aneurysms (p=0.026). The tested differences in the percentage representation of small, large, and giant aneurysms in the groups of ruptured and unruptured showed that small aneurysms were insignificantly more frequently bleeding – 44 (77.19%) vs 13 (56.52%), p=0.06; large aneurysms were insignificantly more frequently non-bleeding – 6 (26.09%) vs 12 (21.05%), p=0.62; and giant aneurysms were significantly more frequently non- bleeding – 4 (17.39%) vs 1 (1.75%), p=0.0089 (Table 3).

Table 3: Statistical analysis of patients with ruptured and unruptured brain aneurysms by location and size.

Variable		Ruptured Aneurysm			p - value	
		n	Yes n (%)	No n (%)		
Location	Anterior	78	55 (96.49)	23 (100)	X^2=0.8 p=0.36	
	Posterior	2	2 (3.51)	0		
Size	Small	57	44 (77.19)	13 (56.52)	Fisher's exact test *p=0.026	[1]p=0.06
	Large	18	12 (21.05)	6 (26.09)		[1]p=0.62
	Giant	5	1 (1.75)	4 (17.39)		[1]*p=0.0089

[1]p(difference two proportions)
*p<0.05, **p<0.01

In 63 (78.75%) patients, only the coiling intervention was performed, while the remaining 17 (21.25%) patients underwent a combined method in addition to coiling (7 had a stent placed, 10 had a flow diverter). Coiling as the sole method-intervention was significantly more frequently performed in patients with ruptured aneurysms – 52 (91.23%) vs 11 (47.83%), p=0.000017.

Regarding other applied interventions, 5.26% of patients with ruptured and 17.39% of patients with unruptured aneurysms had a stent placed; 3.51% of patients with ruptured and 34.78% of patients with unruptured aneurysms underwent intervention with a flow diverter.

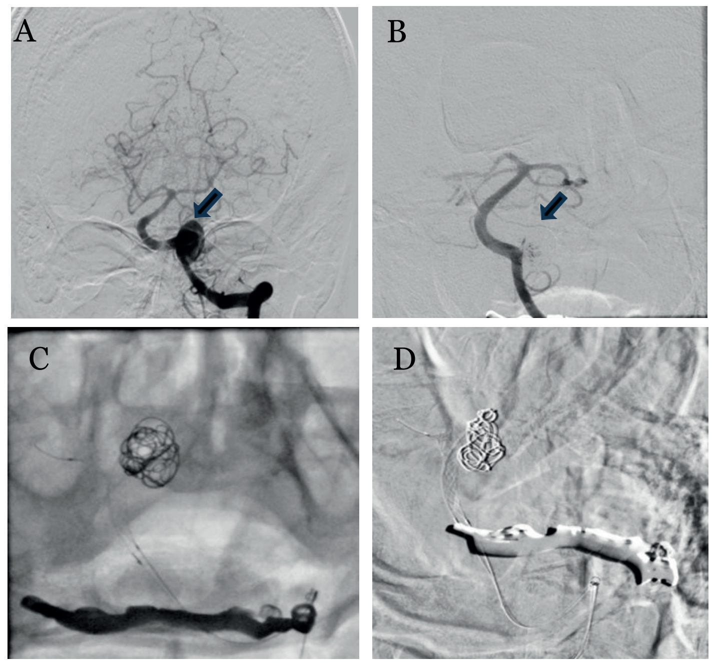

Figure 1: Endovascular treatment of a 68-year old patient with bleeding large wide-necked saccular aneurysm at the exit of the left PICA from the vertebral artery a. DSA imaging of the aneurysm in the left vertebral artery. b. Complete exclusion of the aneurysm from the vascular bed with neck coverage. c, d. Depiction of the noncompletely occlusive net-assisted remodeling technique with coils and filling of the sac.

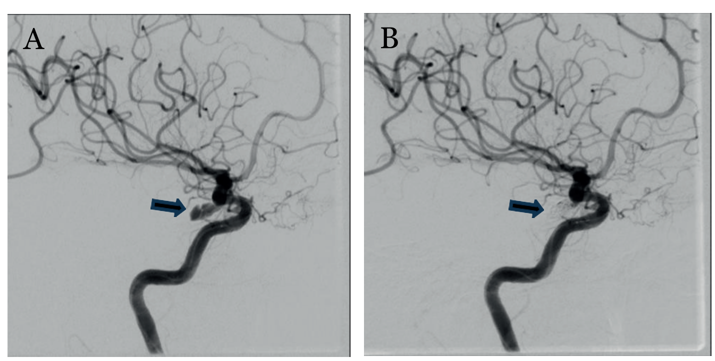

Figure 2: Endovascular treatment, coiling of a 78 year-old female patient with bleeding large saccular aneurysm on the communicating segment of the left internal carotid artery (ICA). a. DSA imaging of the aneurysm of the left ICA. b. Complete exclusion of the aneurysm from the vascular bed with coils and neck coverage.

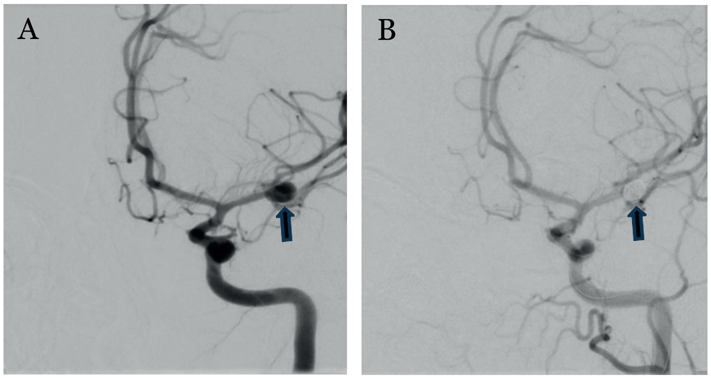

Figure 3: Endovascular treatment, coiling of a 35 year old female patient with bleeding large saccular aneurysm on the bifurcation, M2 segment of the left middle cerebral artery (MCA). a. DSA imaging of the aneurysm in the left MCA. b. Complete exclusion of the aneurysm from the vascular bed with coils and neck coverage.

Recanalization was performed in 13 (16.25%) patients**,** including 7 (12.28%) patients with ruptured and 6 (26.09%) patients with unruptured aneurysms, without statistically significant difference (p=0.3). Repeat treatment due to recanalization or bleeding complications was performed in 7 (8.75%) patients. Bleeding complications occurred in 18 (22.5%) patients, while procedural complications were recorded in 5 (6.25%) patients. Bleeding complications were present in 18 (31.58%) patients with ruptured aneurysm, including various degrees of vasospasm, cerebral edema, recurrence of SAH, hemiparesis, hemiplegia, infarction, and death (Table 4). During the intervention or in the early post-intervention phase up to 6 months, 4 patients died, resulting in a lethality rate of 5%. All deceased patients had ruptured aneurysms.

Table 4: Statistical analysis of patients with ruptured and unruptured brain aneurysms by type of intervention, complications, and re-endovascular treatment.

Variable		Ruptured Aneurysm			p-value
		n	Yes n (%)	No n (%)	
Hydrocephalus	Yes	9	9 (15.79)	0	X^2=4.09 *p=0.043
	No	71	48 (84.21)	23 (100)	
Intervention	Coiling	63	52 (91.23)	11 (47.83)	X^2=18.45 ***p=0.000017
	Coiling + Other (Stent)	17	5 (8.77)	12 (52.17)	
Recanalization	Yes	13	7 (12.28)	6 (26.09)	X^2=2.3 p=0.3
	No	67	50 (87.72)	17 (73.91)	
Bleeding Complications	Yes		18 (31.58)		
	No		39 (68.42)		
Complications During Intervention	Yes	5	4 (7.02)	1 (4.35)	X^2=0.2 p=0.66
	No	75	53 (92.98)	22 (95.65)	
Re-endovascular Treatment	Yes	7	3 (5.77)	4 (20)	X^2=3.33 p=0.068
	No	65	49 (94.23)	16 (80)	

X^2 (Pearson Chi-square)

During the intervention, complications were recorded insignificantly more frequently in patients with ruptured aneurysms – 4 (7.02%) vs 1 (4.35%), p=0.66. Re-endovascular treatment due to recanalization or bleeding was indicated more often in patients without ruptured aneurysms – 4 (20%) vs 3 (5.77%), but the difference was not sufficient to be confirmed as statistically significant (p=0.068). The occurrence of hydrocephalus was recorded only in patients with ruptured aneurysms, in 9 (15.79%) patients (Table 4).

Discussion

Since it was approved by the U.S. Food and Drug Administration in 1995, endovascular treatment has become the primary method of treating brain aneurysms in numerous centers [10]. The aim of endovascular procedures is to achieve dense packing and promote rapid coagulation in the aneurysm sac, thereby isolating it from active circulation. The geometry of the aneurysm is important for the treatment decision and outcome. Coiling alone is the typical treatment for brain aneurysms with favorable anatomical characteristics. For more complex aneurysms that exhibit unfavorable anatomy, additional techniques with stenting and flow diversion may be used in treatment. When treating complex aneurysms with a wide neck, it is difficult to achieve coil stability and dense packing, so balloons and various types of stents are used. The multicenter CLARITY study showed an equivalent rate of complications in endovascular treatment and the overall morbidity and mortality associated with treatment in different endovascular approaches, with coiling alone or with additional devices [10].

In the study, the female gender (60%) predominated over the male gender, which differs from various published studies. The age of patients of both genders did not differ significantly, although females had a slightly higher average age compared to males (57.7 ± 10.1 years vs 53.5 ± 10.1 years). However, ruptured aneurysms were more frequently diagnosed in males (84.38%) compared to females (62.5%), which was statistically significant. Studies have been published showing a higher incidence of aneurysms in male adolescents, while the dominance is greater in women during adulthood [3]. Female gender is an independent risk factor for the growth and rupture of aneurysms, and the lack of estrogen, especially in postmenopausal women, has a significant impact on the pathophysiology of aneurysm formation and rupture [11,12].

Estrogen has been shown to affect vascular endothelial function and improve the normal physiological vascular system. By preserving vascular integrity, estrogen in young adult women appears to play a significant protective role in aneurysm formation and rupture. Thus, ruptured aneurysms were more dominant in young adult males with relatively low levels of estrogen compared to females [11]. The type of bleeding did not differ significantly between genders, which is consistent with previous reports indicating that gender is not a significant factor for the type of bleeding [13].

The localization of aneurysms was similar between both genders. Both posteriorly localized aneurysms were diagnosed in 1 female and 1 male (p=0.77). Anteriorly, the most common localization in females was the ICA (25%), while in males it was the ICA and ACOM (37.5%). These findings are consistent with previous studies indicating no significant differences in the localization of aneurysms between genders [14]. The size of aneurysms also did not differ significantly between female and male patients (p=1.0). The most common size of aneurysms was small (71.25% in females and 71.88% in males), which is similar to previous findings in the literature. This confirms the findings of Smith and colleagues [15] that the size of the aneurysm does not always correlate with the risk of rupture.

Our study showed that aneurysms localized in the ICA were more frequently unruptured (61.54%), while aneurysms from other localizations were more frequently ruptured, with the highest prevalence in ACOM (81.82%) and PICA (100%). Differences in the distribution of ruptured/unruptured aneurysms between ICA and ICA-PCOM (p=0.039), and ICA and ACOM (p=0.024) were statistically significant. These results are consistent with the findings of Wiebers et al. [16] from the ISUIA study, indicating that the location of the aneurysm is a critical factor for the risk of rupture. The incidence of aneurysm rupture in patients younger than 40 years is 10-20% [17]. Young adult patients with ruptured aneurysms usually show good prognosis with rare cases of perioperative mortality. Clinical outcomes are generally favorable due to the low incidence of hydrocephalus, severe vasospasm, and other medical issues [14,17,18].

Bleeding complications were most common in aneurysms localized in PICA (75%) and ICA (60%), but were not statistically significant. Complications during intervention did not show significant differences depending on localization (p=0.79). These findings are consistent with the study by van Gijn et al. [19], indicating that complications in aneurysm treatment are complex and depend on multiple factors, including localization. The type of bleeding did not show significant differences depending on the localization of aneurysms (p=0.192). However, subarachnoid hemorrhage was the most common type of bleeding in aneurysms localized in ICA (80%), which is consistent with the study by Brisman et al. [20], indicating that subarachnoid hemorrhage is the most common type of bleeding in ruptured aneurysms. The prevalence of hydrocephalus was highest in aneurysms localized to PICA (50%) and ICA-PCOM (20.83%), with no significant difference depending on localization (p=0.095). These results are consistent with the findings of Connolly et al. [21], which indicate that hydrocephalus is a common complication in the rupture of aneurysms, but does not depend significantly on localization. In terms of treatment, coiling was more commonly applied in men (90.63%) compared to women (70.83%). This difference may be due to different clinical approaches and treatment recommendations based on gender [22].

Bleeding complications were significantly more common in men (48.15%) compared to women (16.67%) (p=0.01), which could be a subject of further research to understand the potential mechanisms behind this difference. The findings indicate the importance of detailed analysis of the demographic and clinical characteristics of patients with aneurysms for optimizing treatment. Although no significant differences in localization and size of aneurysms were observed between genders, differences in treatment application and bleeding complications suggest a need for further research to improve clinical guidelines and recommendations. Brain aneurysms differ in their localization, including the frequency of rupture, type of bleeding, occurrence of hydrocephalus, type of intervention, occurrence of recanalization, complications, and patient outcomes. Coiling was the primary intervention in 78.75% of patients, while other interventions (including stent placement and flow diversion) were applied in the remaining cases. The advantage of coiling is supported by its minimally invasive nature and favorable outcomes in aneurysm treatment [10,23].

The type of intervention significantly varied depending on the size of the aneurysm. Coiling intervention was predominantly more common in patients with small aneurysms (92.98%), while other interventions, including stenting and flow diversion, were more common in patients with large and giant aneurysms [24]. This distribution reflects the general trend reported in the clinical literature, where small aneurysms are more frequently diagnosed due to improved imaging techniques [8]. Coiling intervention was most commonly performed in aneurysms localized to ACOM (100%), PICA (100%), and MCA (85.71%). Differences in the distribution of interventions among different localizations were statistically significant (p<0.05). These findings are consistent with the study by Molyneux et al. [22], which indicates that the choice of intervention may vary depending on the localization and characteristics of the aneurysm.

Bleeding complications were observed in 22.5% of patients, and intraoperative complications in 6.25%, which are relatively comparable to complication rates reported in existing studies [25]. Regarding complications during the intervention, no statistically significant difference was found between groups with small, large, and giant aneurysms. Complications during the intervention were registered in 7.02% of patients with small aneurysms and in 5.56% of patients with large aneurysms [26]. Recanalization occurred in 16.25% of patients, which is within the expected range for this type of intervention. Recanalization was most common in aneurysms localized to ICA (30.77%) and ICA-PCOM (25%), but the difference was not statistically significant (p=0.196). These results are consistent with the findings of Pierot et al. [27], which indicate that recanalization is a common issue in aneurysm treatment, without significant dependence on localization.

The average age of patients in our study with and without recanalization was 59.5 ± 8.1 and 55.4 ± 10.6 years, respectively, without a statistically significant difference (p=0.195). Studies by Moore et al. [28] have shown similar results, where recanalization is not significantly associated with patient age. Recanalization was most frequently performed in patients with giant aneurysms (80%), followed by large (22.22%) and small aneurysms (8.77%). A statistically significant difference was observed in the distribution of patients with and without recanalization depending on the size of the aneurysm (p<0.0001) [29].

The results of this study highlight the importance of accurately assessing the size and localization of aneurysms in determining risk factors and selecting interventions. These findings can contribute to improving treatment and prevention strategies, aiming to reduce complications and improve outcomes in patients with cerebral aneurysms [30]. The mortality rate in the early post- intervention phase was 5%, a figure reflecting the inherent risks of aneurysm treatment and the critical condition of many patients [13]. Mortality did not show significant differences depending on the localization of aneurysms (p=0.74), consistent with the findings of Naggara et al. [13], who indicate that aneurysm mortality depends on multiple factors, not just localization. Re- endovascular treatment also did not show significant differences depending on localization (p=0.232), consistent with the study by Cloft et al. [31]. Re-endovascular treatment was most often indicated in patients with giant aneurysms (60%), followed by patients with large (13.33%) and small aneurysms (3.85%). The differences in the frequency of re-endovascular treatment are statistically significant, indicating that the size of the aneurysm influences the need for additional interventions [23]. These analyses show that the size of the aneurysm has a significant impact on the need for re-endovascular treatment but is not a significant factor in predicting bleeding complications and lethality. These findings may be useful in improving treatment strategies and management of patients with cerebral aneurysms [30]. These findings emphasize the importance of early diagnosis and treatment of aneurysms, especially in older adults. The high prevalence of hypertension among patients highlights the need for aggressive management of this risk factor to prevent aneurysm formation and rupture. Further research is needed to optimize treatment strategies and improve patient outcomes, particularly in managing large and giant aneurysms.

Conclusion

Endovascular treatment of brain aneurysms is a minimally invasive method of choice with optimal benefit for patients during the procedure and in the post-therapeutic period, contributing to full recovery. This treatment of brain aneurysms is increasingly becoming the first option for treatment, given that it can be performed on aneurysms with unfavorable morphometric characteristics and localization, which are not suitable for surgical treatment. The role of endovascular procedures represents a complete diagnostic and therapeutic revolution in the diagnosis and treatment of cerebral aneurysmal changes, both in their early detection and in the complete management and treatment of this condition.

The method has been used relatively recently in clinical practice, so research in the field is important. The results of published studies emphasize the complex interaction of demographic, anatomical, and clinical factors in the management and outcomes of ruptured and unruptured aneurysms. Research and meta-analyses can help improve risk assessment models and tailor patient-specific treatment strategies, ultimately improving prognosis and reducing the incidence of adverse outcomes. In the coming years, artificial intelligence is at the forefront of revolutionary evaluation and treatment of intracranial aneurysms. Certain AI algorithms can improve the accuracy of aneurysm detection and characterization, helping physicians in diagnosis and treatment planning, risk assessment of rupture, and prioritizing clinical therapy strategies.

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